

Overview of TCV Results

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The *Tokamak à Configuration Variable*, TCV, addresses on one hand the scientific questions that have been recognized to limit our understanding of magnetically confined plasmas and our ability to control them in ITER relevant scenarios, and explores, on the other hand, avenues to improve the plasma performance on the way to a conceptual fusion power plant that can't necessarily be addressed by an integrated experiment such as ITER. The flexibility of its shaping and control systems, which make TCV a unique research tool worldwide, is matched by that of its Electron Cyclotron Heating (ECH) and current drive (ECCD) systems. These include 3MW from six 82.7GHz gyrotrons used at the second harmonic in X-mode (X2), and 1.5MW from three gyrotrons at 118GHz (X3).

This overview highlights the progress accomplished on TCV during the 2004-2006 campaigns, focussed on five main themes: 1) particle, energy and momentum transport in shaped plasmas, 2) plasma edge physics, 3) H-mode physics under strong electron heating at reactor relevant β , 4) ECH and ECCD physics, including electron Bernstein waves, 5) physics of improved steady-state tokamak regimes with internal transport barriers and large non-inductive current fractions.

Peaked density profiles are measured on TCV in the absence of a Ware pinch or a core particle source, indicating the essential role of anomalous processes. The density profile flattening observed with additional core electron heating saturates for a total power exceeding the Ohmic power by more than a factor of three, suggesting that in a burning plasma, with strong core electron heating from fusion produced α 's, the density profiles may remain peaked, improving the fusion power output [1].

The influence of the plasma shape on energy confinement and electron heat diffusivity, χ_e , was investigated in a wide range of plasma collisionalities, ν_{eff} , including low density EC heated plasmas, with localized EC deposition outside the $q=1$ surface. For large values of normalized temperature gradient ($R/L_{Te} > 10$), TCV data indicates that χ_e decreases significantly as the plasma triangularity is decreased (δ from +0.4 to -0.4). The measured scaling of χ_e with T_e , density and effective charge is compatible with χ_e depending on these parameters only via ν_{eff} . An important role of TEM in electron heat transport is suggested by linear gyro-fluid and gyro-kinetic models, which predict that TEM are the most unstable modes in these plasmas, and that their stability depends on ν_{eff} and δ in a qualitatively similar way as the measured electron heat transport [2].

The question of the origin of anomalous cross-field transport in the SOL was addressed by comparing fast (MHz) fluctuation measurements obtained using a reciprocating Langmuir probe in various shapes, configurations and confinement regimes, with the predictions of a state-of-the-art fluid code. The data on single-point density fluctuations and ExB driven turbulent fluxes are in agreement with the code calculations and are interpreted as resulting from interchange motion, producing filamentary plasma 'blobs', rapidly advected (100-200m/s) in the SOL [3].

Third harmonic X3 heating (1.5MW) was applied to ELMy H-modes [4], leading to plasma β up to 2.5% ($\beta_N \sim 2$) with large type I ELMs. Central ion and electron temperatures increase from $\sim 500\text{eV}$ to $\sim 1\text{keV}$, and from $\sim 1\text{keV}$ to $\sim 2.5\text{keV}$. At high β the plasma may enter a quasi-stationary ELM-free H-mode lasting for many energy confinement times, with the same densities as ELMy discharges and significantly lower particle confinement than transient ELM-free H-modes. The plasma toroidal rotation increases significantly at the onset of the quasi-stationary ELM-free H-mode [5].

A distinct electron supra-thermal population is observed during strong EC heating and following sawtooth crashes. Different ECH-ECCD scenarios, including X3 vertical injection, are used to manipulate the electron distribution and study its dynamics. Low duty cycle EC bursts and coherent averaging of the relevant signals provide information on rf diffusion of fast electrons, their collisional slowing-down and pitch angle scattering in velocity space, as well as on their real space transport. Electrons accelerated by electric fields associated with the magnetic reconnection occurring at sawtooth crashes are observed to undergo a very rapid cross-field transport [6].

The limitation to the plasma density that can be accessed by O- and X-mode EC can be circumvented by using Electron Bernstein Waves (EBWs), which are not subject to cut-off. The $O \rightarrow X \rightarrow B$ scheme is used, with the large densities and gradients necessary for the $O \rightarrow X$ conversion obtained in diverted H-modes with $\delta \sim 0.55$ and $q_{95} \sim 2.5$. High power experiments (up to 2MW) were performed at the optimum O-mode injection angle, determined by minimizing the stray field. T_e increases of $\sim 10\%$ are measured, with global absorption fractions up to 60% (from the diamagnetic loop) and a power deposition profile (from a 64-channel soft X-ray camera) peaked at a location where the density exceeds the O-mode cut-off, which constitutes a clear signature of EBW heating [7].

Electron Internal Transport Barriers (eITBs) are obtained on TCV with strong ECCD in nearly or fully non-inductive scenarios, in cases with comparable ohmic and non-inductively driven currents, and, transiently, in the absence of current drive by strong heating during current ramps. Significant (up to a factor of 6) improvements in confinement compared to TCV L-mode scaling characterize all these conditions, with strongly correlated barriers in n_e and T_e . Recent experiments, in which small current perturbations are produced inductively with negligible energy input, confirm the key role of the current profile in the transition to improved confinement. A negative magnetic shear at the center is crucial for obtaining eITBs, whose strength increases for increasing magnitude of the shear. In addition, the smooth dependence of the confinement enhancement on the perturbative loop voltage indicates that no special role is played by rational q-surfaces in the barrier formation (at least in the range $1.3 < q < 2.3$). In the presence of eITBs, bootstrap current fractions reach values in excess of 70% [8].

- [1] H.Weisen et al., this Conference
- [2] Y.Camenen et al., this Conference
- [3] R.A.Pitts et al., this Conference
- [4] Y.Martin et al., this Conference
- [5] L.Porte et al., this Conference
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